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Research Department Report

ANTENNAS FOR PORTABLE VHF-FM RECEIVERS

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Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

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Summary

This Report describes a number of compact antennas which have been considered as replacements for the standard whip antenna which is normally fitted to VHF portable receivers. A comparison made of their characteristics shows that, of the antennas considered in the survey, the quarter-wave whip still provides the best sensitivity. However the normal-mode helix is a more convenient and compact antenna and is shown to perform better than a short whip of the same axial length. This antenna can be easily engineered to operate over the VHF band and has sufficient sensitivity for normal use.

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1. INTRODUCTION

The FM stereo network in the UK is expanding, with the building of additional transmitter stations providing coverage to hitherto unserved areas of the country. Existing transmitter stations are being re-engineered in a programme which started in 1984. In addition, the Radio 1 FM stereo service is rapidly coming on the air and is already available to over 75% of the population.

Improvements in reception by car radios and portable receivers have been achieved by the introduction of mixed polarised transmissions from the new and re-engineered transmitting stations. Additionally the introduction of the Radio Data Service (RDS) (at the 1988 Radio Show) is expected to provide easier tuning and programme identification. Receivers with additional facilities will help the non-technical listener find the services he or she wants, whether in the home, or on the move in a vehicle.

As moderately priced hi-fi equipment has become widely available for the domestic market, the general public have become more aware of the better audio quality and consistency of service obtainable from the reception of FM broadcasts when compared with that from reception of medium and long-wave broadcasts in the home. However, since the start of the VHF Band II FM transmissions, there has been a reluctance on the part of the public to use the broadcast FM services as fully as they deserve. This is partly because of the need to use antennas mounted at roof level to obtain the best performance, which is only applicable to fixed receivers in the home. Also, more recently, with the increasing number of transmissions in the VHF band, many listeners have found difficulty in locating the station of their choice on the tuning dial; this will increase as the band is extended to cover 88 to 108 MHz in the near future.

Even with the reduction in cost of domestic receivers providing both AM and VHF-FM reception, the popularity of the portable VHF receiver has not been as great as was anticipated. Although the RF performance of many such receivers leaves much to be desired, the greatest objection seems to spring from the need to use the standard telescopic whip antenna for VHF reception. The antenna is approximately $\lambda/4$ long when fully extended, is an awkward mechanical arrangement, and often obstructs the user's movements in the vicinity of the receiver. Within the home environment it is often necessary to re-position the whip to regain acceptable reception following a change of programme channel. The whip antenna can, in an extreme case, present a hazard to the listener and because of this, it is often used at reduced length resulting in a severe reduction in sensitivity.

The ideal antenna for a VHF portable receiver should be compact and, if possible, incorporated into the body of the receiver in a similar way to the ferrite-rod antenna used for medium and long-wave reception.

An investigation has been carried out in which several types of antenna have been considered with the specific objective of replacing the conventional whip with more robust and compact designs without unduly sacrificing performance.

The performance of the antennas when used with a portable receiver within the home is somewhat nebulous, in that the sensitivity usually depends on the receiver acting as a counterpoise for electric field sensitive antennas, and it is influenced by nearby metal objects. Some improvement in reception can be made by increasing the metal content of the receiver itself.

This Report presents the results of measurements on some familiar types of antenna when used in the VHF broadcast band and describes their features.

2. ANTENNAS CONSIDERED IN THE STUDY

The whip is the standard antenna fitted to nearly all VHF-FM portable receivers manufactured for the domestic market. The whip when fully extended is approximately $\lambda/4$ long (at mid-band 0.78 m), and the arrangement on most receivers allows the whip to be set at almost any angle of inclination between horizontal and vertical. Similar facilities would be desirable for the other compact antennas considered as replacement for the $\lambda/4$ whip. Amongst the antennas considered for this purpose were the short whip, ferrite, frame, and the normal-mode helix. Table 1 shows a comparison of their characteristics, with the sensitivity of each type of antenna compared with that of an idealised $\lambda/2$ dipole.

It can be seen from Table 1 that the $\lambda/4$ whip antenna is the most sensitive of the five antennas considered. Its performance is broadband, but even so,

Table 1: Antenna characteristics

Antenna	$\lambda/4$ whip	Short whip	Ferrite	Frame	Helix
Ideal sensitivity (dB wrt a $\lambda/2$ dipole)	−3	−25	−23	−22	−10
Bandwidth (3 dB, MHz)	Broad	Broad	3.2	2.0	9.0
Tuning required	No	No	Yes	Yes	Yes
Cost	Low	Low	High	Moderate	Moderate
Convenience	Awkward; Can cause injury	Compact	Compact; Fragile	Compact; Not easily rotated	Compact; Robust

it is less sensitive at the upper and lower ends of the band due to impedance mismatch. When the whip is fitted to a receiver having an input impedance of 50 Ω the loss at the band edges increases by approximately 3 dB, reducing its sensitivity to 6 dB below that of a $\lambda/2$ Dipole.

2.1 The short whip antenna

The short whip antenna (approximately 260 mm long) connected directly to a 50 Ω receiver input has a low sensitivity because of mismatch loss. The self-impedance of a short whip is largely reactive, its magnitude depending on its length and diameter. For a short whip of reasonably acceptable dimensions the self reactance is a few hundreds of ohms. The variation of the sensitivity of the whip with reduction of its length is shown in Fig. 1. Some change of the response of the short whip over the wanted band can normally be expected, in practice it is only a few decibels. This antenna, although relatively small, cannot be fitted inside the portable receiver cabinet because its sensitivity is reduced by the proximity of the metalwork comprising the receiver circuity boards and its components.

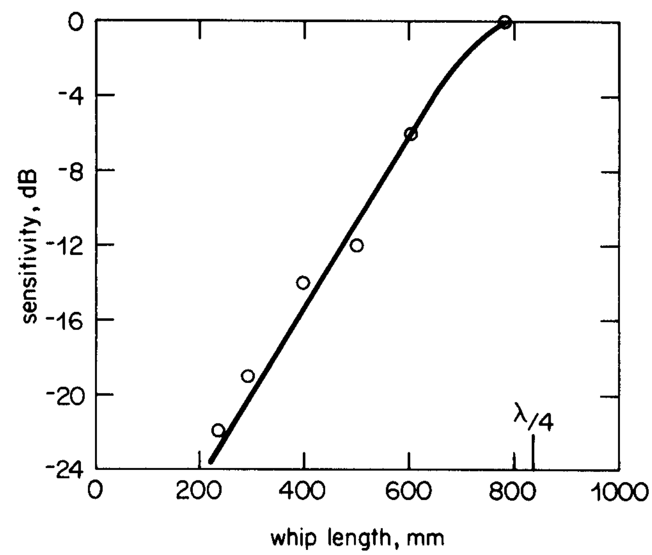


Fig. 1 - Relative sensitivity of a whip antenna on a portable receiver.

o measured values
—— theoretical values

2.2 The ferrite antenna

The ferrite antenna[1] relies on the magnetic field for its pick up. The matched output with zero losses would be equal to that of a matched doublet element, which has the same omnidirectional radiation (sensitivity) pattern in one plane and a cosinusoidal radiation pattern in the other; its intrinsic gain being −0.4 dB relative to that of a $\lambda/2$ dipole. However, the losses in the ferrite material and tuning capacitors reduce the matched output to −23 dB below that of a $\lambda/2$ dipole. Its bandwidth depends on its circuit losses and for a good ferrite material, usually a nickel/zinc ferrite, which has a typical initial permeability of between 12 and 30 and a loss factor $(\tan \delta)/\mu_i$ of around 2×10^{-4}, this is only a few megahertz wide in the VHF band. The ferrite antenna tuning must track reasonably accurately with the receiver tuning because of this relatively narrow bandwidth. Some improvement in sensitivity[2] can be obtained by using a larger ferrite core than considered here, but the penalty is increased size and weight of material. Because of the complexity of the tuning and coupling circuits of this antenna it is probably one of the more expensive arrangements to employ. A disadvantage of this antenna is that the electrical characteristics of the ferrite material can be permanently impaired by mechanical shock and strong magnetic field. It can be

fitted within the body of the receiver without impairing its sensitivity, although in synthesised receivers pick up of the magnetic fields associated with currents in the digital processing circuits needs to be avoided. It should, of course, be kept away from the strong fields of loudspeaker magnets.

2.3 The frame antenna

The frame antenna shows much the same performance as the ferrite antenna. Its sensitivity, shown in Table 1, is dependent on its circuit Q, which is governed by the skin effect losses in the frame conductor and the tuning capacitor losses. It is possible with a single-turn, thick conductor loop to obtain a Q which is larger than necessary making the receiver tracking difficult and the passband width inadequate. A frame antenna could be fitted within the receiver cabinet but because of its physical size it is probably more suited to being mounted on the cabinet's exterior. Although the loop could be shaped to form a handle for the portable receiver it would not be a particularly practical arrangement as the close proximity of a hand would de-tune the loop to some extent.

2.4 The helix antenna

The normal-mode helix provides the best sensitivity of all of the compact antennas. It is a slow-wave structure, the velocity ratio of the helix tried in this work being about 4:1, and it is the only one of the compact antennas which in theory, can respond to unwanted cross-polar field components. However, for these experimental helices the ratio of sensitivity to horizontally polarised signals compared with that of vertically polarised signals, calculated using an approximate theory[3], is −26 dB. Its bandwidth is moderate and for the test helix this was 9 MHz between the 3 dB sensitivity points. For a helix resonating at the centre of Band II its sensitivity falls by 10 dB at the band edges. This is a problem which can be overcome by tuning the helix with external components.

3. MEASUREMENTS OF ANTENNA SENSITIVITY

To test the predictions of sensitivity, a group of antennas were made and tested. The antennas tested were the short whip, ferrite-rod, normal-mode helix, and frame antenna.

Their sensitivities were measured by immersing them in a known electric field generated within a TEM-mode cell, using a tracking generator and spectrum analyzer. Each antenna, while under test, was connected via a co-axial feeder to the 50 Ω input of the spectrum analyzer. The arrangement is shown in Fig. 2.

The short whip was a telescopic whip set to a fixed length of 260 mm as shown in Fig. 3.

The ferrite antenna was a commercially manufactured unit, as used in a paging receiver. A schematic sketch and the circuit are shown in Fig. 4. It consisted of a single turn of copper foil, tuned by multiple variable capacitance diodes. The output from the unit was taken via a coupling coil nominally matched to a 50 Ω output impedance.

The frame antenna, shown in Fig. 5(a), consisted of a rectangular loop 90 mm by 40 mm made from 12.5 mm by 3.5 mm aluminium strip. Impedance matching and loop tuning was by way of a capacitor potentiometer network as shown in Fig. 5(b). Although the impedance transformation produced by the network is not constant with change of frequency because one of the capacitors has a fixed value, the variation of radiation resistance with frequency (proportional to $1/\lambda^4$), introduces some compensation so that the mismatch loss due to this effect at the band edges will be less than 0.1 dB.

The helix was constructed as shown in Fig. 6. It was connected directly to the 50 Ω input impedance

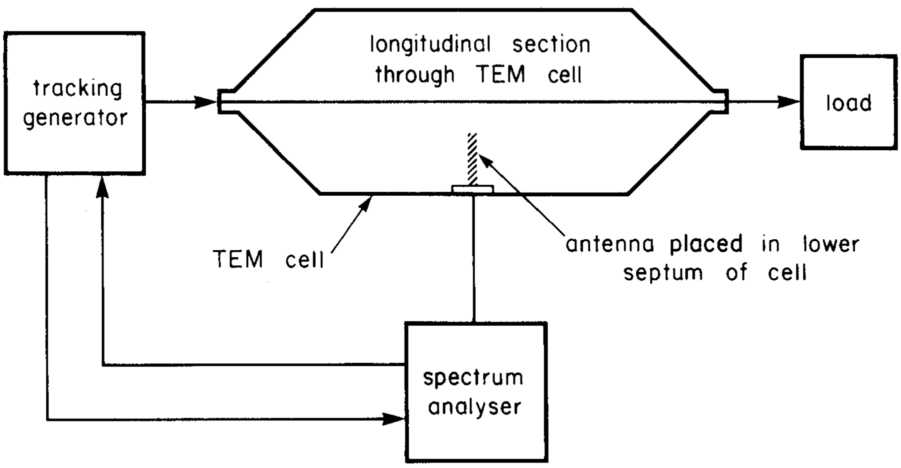


Fig. 2 - Arrangement for measurement of the sensitivity of a compact antenna.

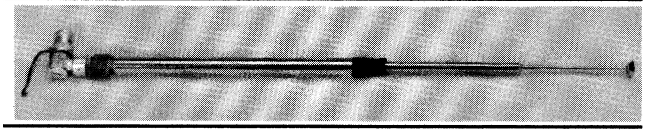


Fig. 3 - The short whip antenna.

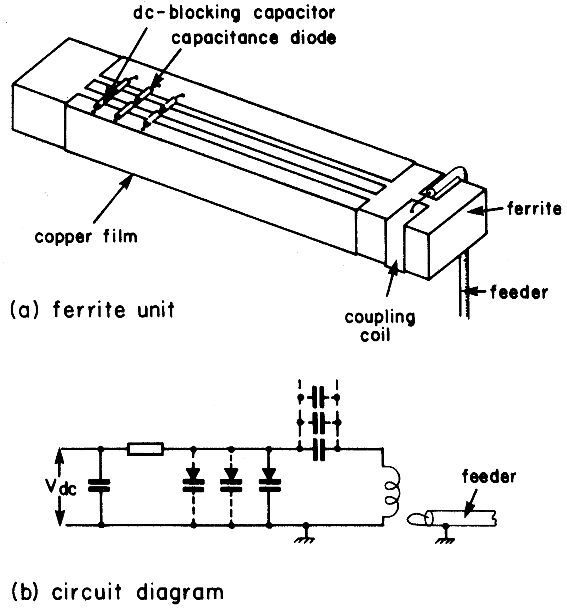


Fig. 4 - The ferrite antenna.

of the spectrum analyzer without an additional matching network.

The measured results showed good agreement with calculated values obtained after taking into account the circuit losses and impedance mismatches. A comparison of the calculated and measured sensitivities at the resonant frequencies of the tuned antennas and at mid-band for the broadband antennas is shown in Table 2. The measured bandwidths have already been included in Table 1.

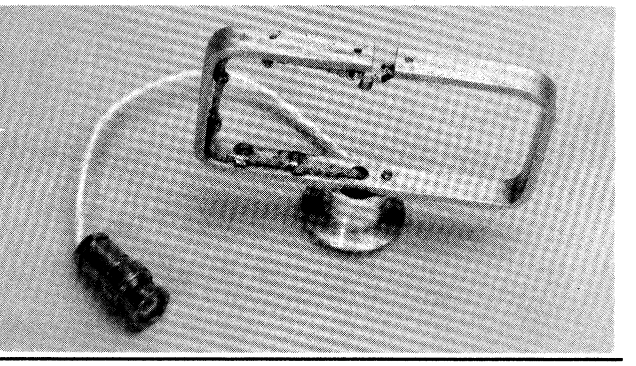
Table 2: TEM cell measurements

Sensitivity, dB with respect to $\lambda/2$ dipole

	Short whip	Ferrite	Frame	Helix
Measured	−25.2	−24.3	−19.6	− 9.9
Calculated	−25.0	−23.0	−22.0	−10.0

These results confirm that the helix has the best sensitivity of all the compact antennas tested. The experimental antenna dimensions are as shown in Fig. 7.

A problem with the helix is that it has limited bandwidth; however it is possible to tune it at



(a)

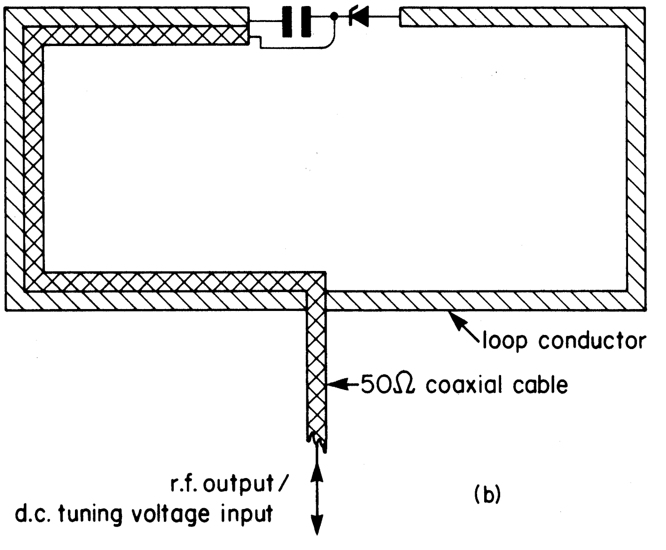


Fig. 5 - The frame antenna.
(a) The experimental frame antenna.
(b) The arrangement for matching and tuning the frame antenna.

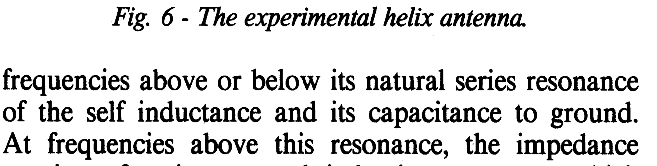


Fig. 6 - The experimental helix antenna.

frequencies above or below its natural series resonance of the self inductance and its capacitance to ground. At frequencies above this resonance, the impedance consists of resistance and inductive reactance which can be made real by the addition of a series capacitive reactance.

At its natural resonant frequency the radiation resistance[4] of this helix is approximately 3.8 Ω. At higher frequencies where tuning is by series capacitance, the impedance match to the receiver input improves because of a transforming effect caused by the self capacitance of the helix windings. This change of impedance match improves the sensitivity of the helix by approximately 1 dB at the higher frequencies. The bandwidth of the helix when tuned in this manner, reduces as the resonant frequency is increased,

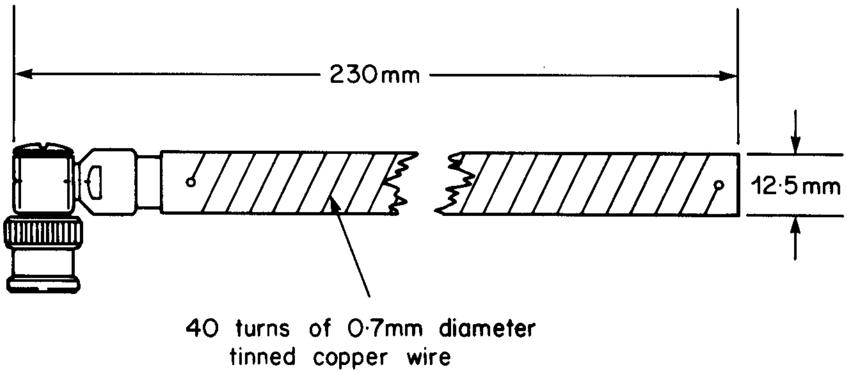


Fig. 7
The dimensions of the experimental normal-mode helix.

and Fig. 8 shows the measured change of bandwidth with resonant frequency.

When fitted to a receiver, the whip and helix antennas rely on the circuit boards and components to act as a counterpoise. Measurements have shown that some improvement in sensitivity is achieved by increasing the area of metal around the receiver itself. Improvements of between 1 dB and 2 dB were observed, the result being an apparent increase in the effective height of the antennas.

4. PRACTICAL ARRANGEMENTS FOR THE HELIX ANTENNA

Ideally the helix should be matched to its load to extract maximum output power, and typically an efficiency of about 65% could be expected after skin effect losses are taken into account.

One way of matching the antenna is to use a tapped coil helix where the bottom end of the helix winding is grounded and an output taken from the tap. The disadvantage of this arrangement is that the tap position as well as the helix length needs to be changed to maintain the match over the band.

Alternatively, a completely mismatched arrangement could be used in which the helix is coupled into a high impedance FET input stage. Typically the input impedance of a dual insulated-gate FET at Band II is about 3.3 kΩ in parallel with 6 pF of capacitance. The helix response becomes less dependent on frequency, but at the expense of considerable reduction in signal-to-noise ratio, the mismatch loss being approximately 22 dB.

The helix antenna can however, be continuously tuned over the band by the addition of a variable capacitance diode in series with its winding. Because the bandwidth is relatively broad, tracking with the receiver tuning is not critical. The tuning voltage could be provided by a look-up table when the helix is used with a synthesised receiver, and by a potentiometer fitted to the tuning capacitor shaft in a mechanically tuned receiver. Alternatively, the tuning could be accomplished by switching fixed value capacitors into the circuit to cover discrete parts of the band. Table 3 illustrates this method and gives the values of capacitance needed to cover the band. It should be emphasised that the values of capacitor shown are those necessary to tune the helix when it is feeding a purely resistive load. Some modification of the capacitance values would be

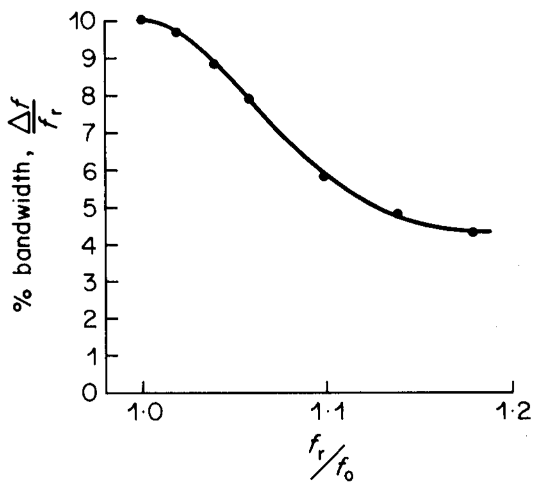


Fig. 8
The bandwidth of the helix when tuned to a frequency above natural resonance.

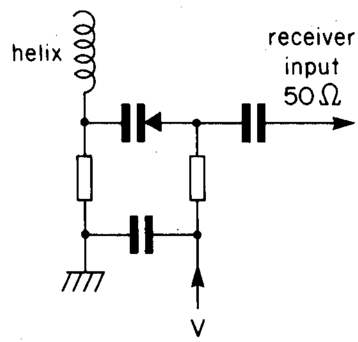


Table 3: *Discrete band tuning for the helix*

Tuned frequency (MHz)	C_t (pf)	Frequency range (MHz)
92	47	87.5 − 96.5
98	11.5	95.1 − 100.9
102	6.3	99.7 − 104.3
106	4.1	103.8 − 108.2

required when the receiver input impedance is not a pure resistance.

Tests have shown a considerable loss of sensitivity when the helix is placed close to the body of the receiver. The difference between the sensitivity of the helix with its windings projecting clear of the receiver body and aligned alongside the receiver body have shown an average reduction of 10 dB. It is essential, therefore, for the helix to be mounted in such a way that the windings project clear of the receiver body while occupying any attitude between horizontal and vertical positions, so that selection can be made of the field component giving the best signal-to-noise ratio and minimum multipath distortion.

5. MEASUREMENT OF THE RADIATION PATTERNS OF THE ANTENNAS WHEN FITTED TO A RECEIVER

Measurements of the radiation patterns of the antennas were made with the antennas fitted to a receiver. The experimental arrangement is shown in Fig. 9. The antenna and receiver were placed on the turntable of an antenna measuring range. The receiver was raised approximately 1 m above the top of the turntable. Facilities for measuring the signal strength from within the boxed receiver were not available, and it was essential that no external connections were made to the receiver as these would alter the receiving characteristics of the combined antenna and receiver. Instead, a small 100 MHz signal source was built into the wooden receiver cabinet and it was connected through a co-axial feeder to the antenna socket. The receiver input terminal was isolated but the earthing connections were maintained to the receiver circuitry. The transmitted signal was received by a distant 'look' antenna on the range and the signal level was measured with a spectrum analyzer. Measurements were made using linear polarisation, both horizontal and vertical.

Measurements of the antennas fitted on the receiver compared reasonably well with the measurements made in the TEM cell. The difference between the received signals from the receiver when fitted with the $\lambda/4$ whip and the helix was 5 dB, this result being within 2 dB of the theoretical value for the $\lambda/4$ whip and the measurement of the helix antenna in the TEM cell. The ferrite antenna could not be measured in this way since most of the source power would have been dissipated in the ferrite and the tuning diodes would have been overdriven. Here a conventional measurement was made with the ferrite unit used as the receiving antenna, connected via a coaxial cable back to the spectrum analyzer. A larger discrepancy arose between the results for the whip and the ferrite antennas in these measurements, the difference between the sensitivity of the two antennas being 18 dB rather than the 21.3 dB obtained in the previous measurements.

The effect of adding a metal ground plane, which covered the base and partially covered one side of the receiver (Fig. 10 shows the receiver with the ground plane by its side), was to give an increase in sensitivity of between 1 and 2 dB when the whip and helix antennas were being used. The radiation pattern of the receiver and helix antenna combination is shown in Fig. 11. In Fig. 12, it can be seen that the radiation (sensitivity) pattern of the ferrite antenna, measured in the conventional way, is symmetric and

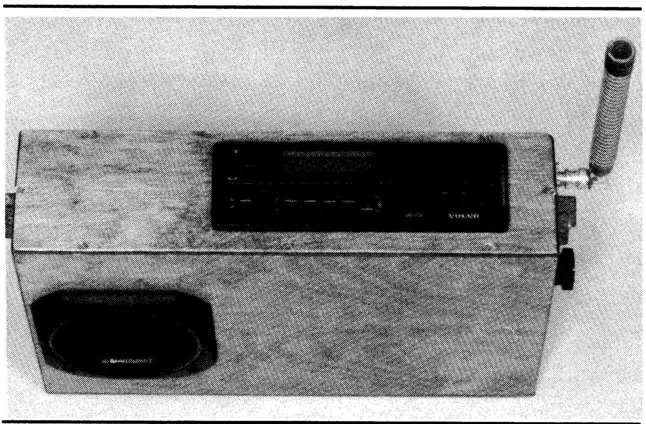


Fig. 9 - The receiver fitted with the helix antenna.

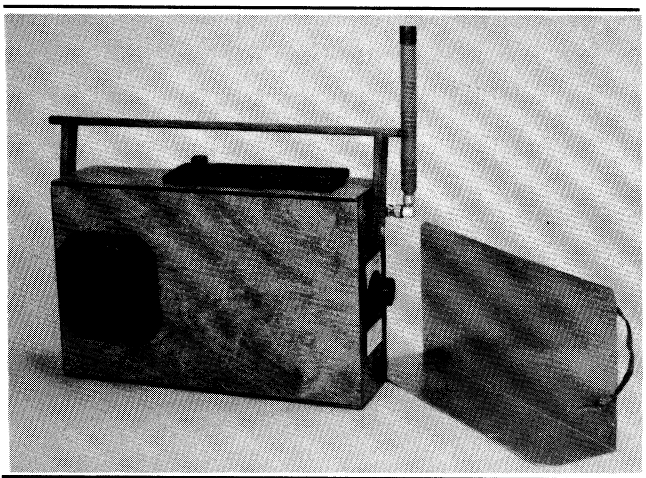


Fig. 10 - The receiver and its counterpoise (ground plane).

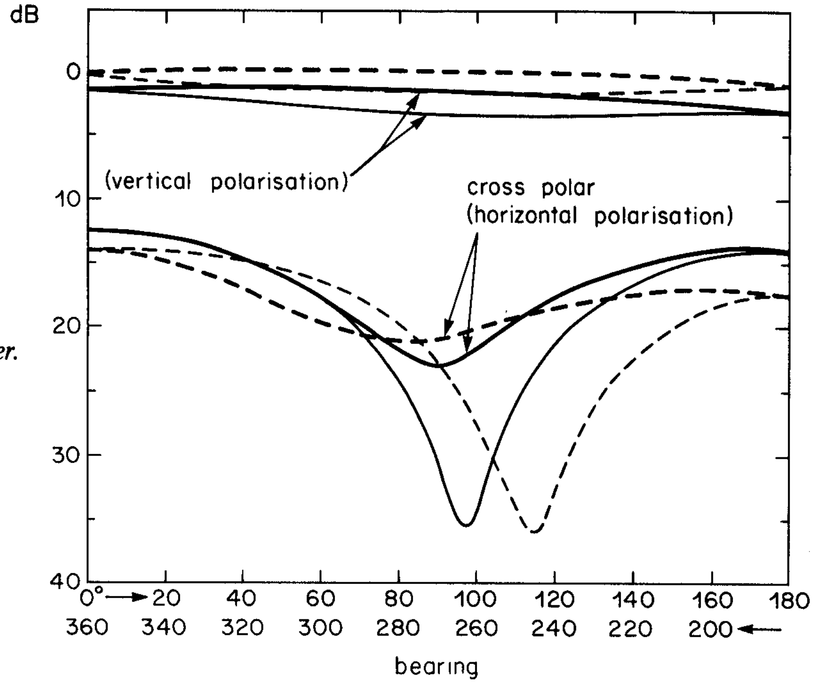


Fig. 11 - HRPs of the helix antenna on the receiver.
- - - receiver with added ground plane
——— receiver without added ground plane

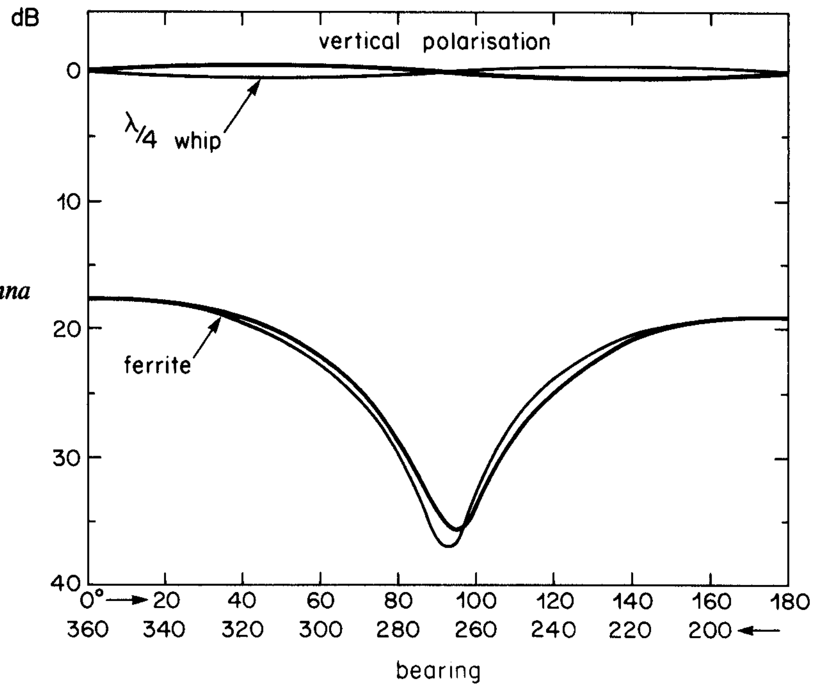


Fig. 12 - HRPs of the quarter-wave whip antenna and the ferrite antenna.

has, therefore, good RF balance. It is less likely to suffer from cross-polar coupling than the electric field sensitive antennas operated with an imperfect ground plane.

6. PORTABLE RECEIVERS IN THE HOME

Reception indoors is degraded by the presence of the building itself and all the usual contents, including people. The propagation environment is not simple. The signal suffers attenuation, its polarisation may be modified, and the reflections cause standing waves. All of these factors affect the reception of the VHF-FM signals indoors.

A series of tests were made to establish the distribution of signal loss within a home, relative to the field strength at a standard height of 10 m outside the building. Some sixty measurements of field strength, both vertically and horizontally polarised, were made in several different houses in a suburban area. An analysis of the building loss gave mean values of 13.6 dB for vertical polarisation and 16.7 dB for horizontal polarisation, with standard deviations of 7.5 dB and 6.7 dB respectively.

Consider a receiver with greater sensitivity than is usual in present-day portable receivers, more typical of a current car radio, having a noise figure of 5.5 dB. This would give a 40 dB weighted signal-to-noise ratio with an input signal level of -122.5 dBW. At the limit-of-service field strength of 54 dB(μV/m), the output from a $\lambda/2$ dipole into a matched receiver is -91.2 dBW. The corresponding output from the helix antenna into a receiver of 50 Ω impedance was 10 dB below that of the $\lambda/2$ dipole, i.e. -101.2 dBW. The difference between the wanted and actual input levels is 21.3 dB, this corresponds to 0.69 and 1.03 standard deviations below the mean levels of the horizontally and vertically polarised components within the buildings. The proportion of locations for which the 40 dB signal-to-noise ratio was achieved and which were considered to be acceptable for portable receiver reception, is 76% and 85% respectively. For the limit-of-service for suburban areas, i.e. a field strength of 60 dB(μV/m), the corresponding proportion of locations giving acceptable reception increased to 94% and 97% respectively.

7. CONCLUSIONS AND RECOMMENDATIONS

This study has shown that reasonably good reception of VHF-FM services can be achieved in the domestic environment using a compact helix antenna with a modern, sensitive receiver. The $\lambda/4$ whip is still the most sensitive of all of the antennas studied in the comparison, but the convenience of the helix, particularly when made in a more flexible form, makes it a very strong contender as the most suitable antenna for the portable receiver cabinet. The addition of metal foil on the inside walls of the receiver cabinet is recommended to improve the performance of the receiver in combination with either the whip or helix antenna.

8. ACKNOWLEDGEMENT

Thanks are due to Messrs. J.L. Riley and M.J. Buckley whose measurements of building loss have been used in this Report.

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